- Lecture 1: Introduction to Smart Materials and Systems
- Lecture 2: Sensor technologies for smart systems and their evaluation criteria.
- Lecture 3: Actuator technologies for smart systems and their evaluation criteria.
- Lecture 4: Piezoelectric Materials and their Applications.
- Lecture 5: Control System Technologies.
- Lecture 6: Smart System Applications.

S. Eswar Prasad,
Adjunct Professor, Department of Mechanical & Industrial Engineering,
Chairman, Piemades Inc,

Piemades, Inc.

Mechanical & Industrial Engineering
UNIVERSITY OF TORONTO

Introduction to Smart Materials and Systems

- The development of Smart Materials and Systems is truly multi-disciplinary science, drawing on expertise ranging from materials science and manufacturing to engineering design and control.
- The most commonly accepted definition is that smart materials and systems can sense and respond to the environment around them in a predictable and useful manner.
- Smart materials and systems have a wide range of applications. Investment in research and development is driven by factors such as legislation, reducing waste and demand for higher quality of life.

Introduction to Smart Materials and Systems

- Definitions
- Need for Smart Systems
- Components of a Smart System
- Overview of Applications

S. Eswar Prasad,
Adjunct Professor, Department of Mechanical & Industrial Engineering,
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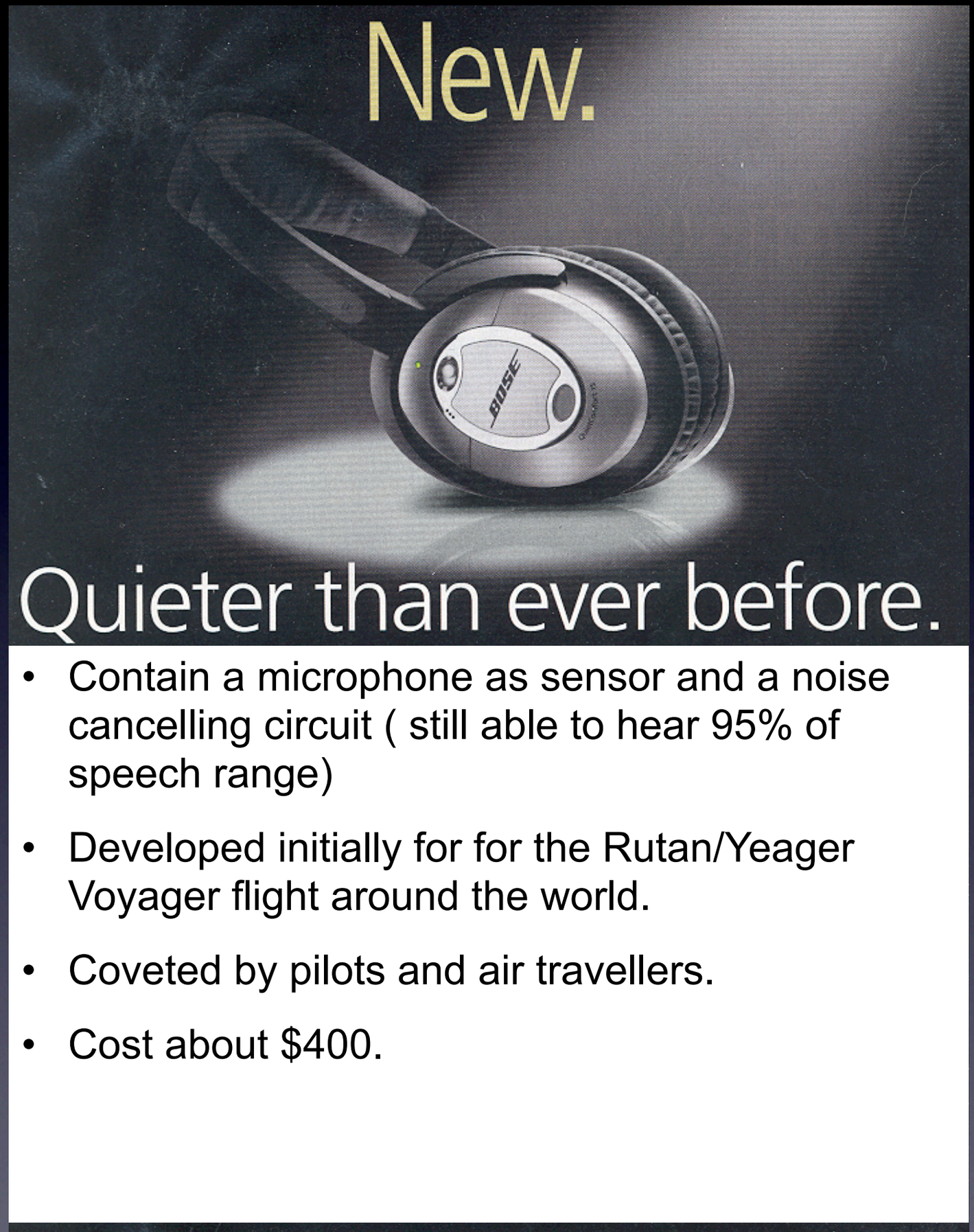
Smart Systems

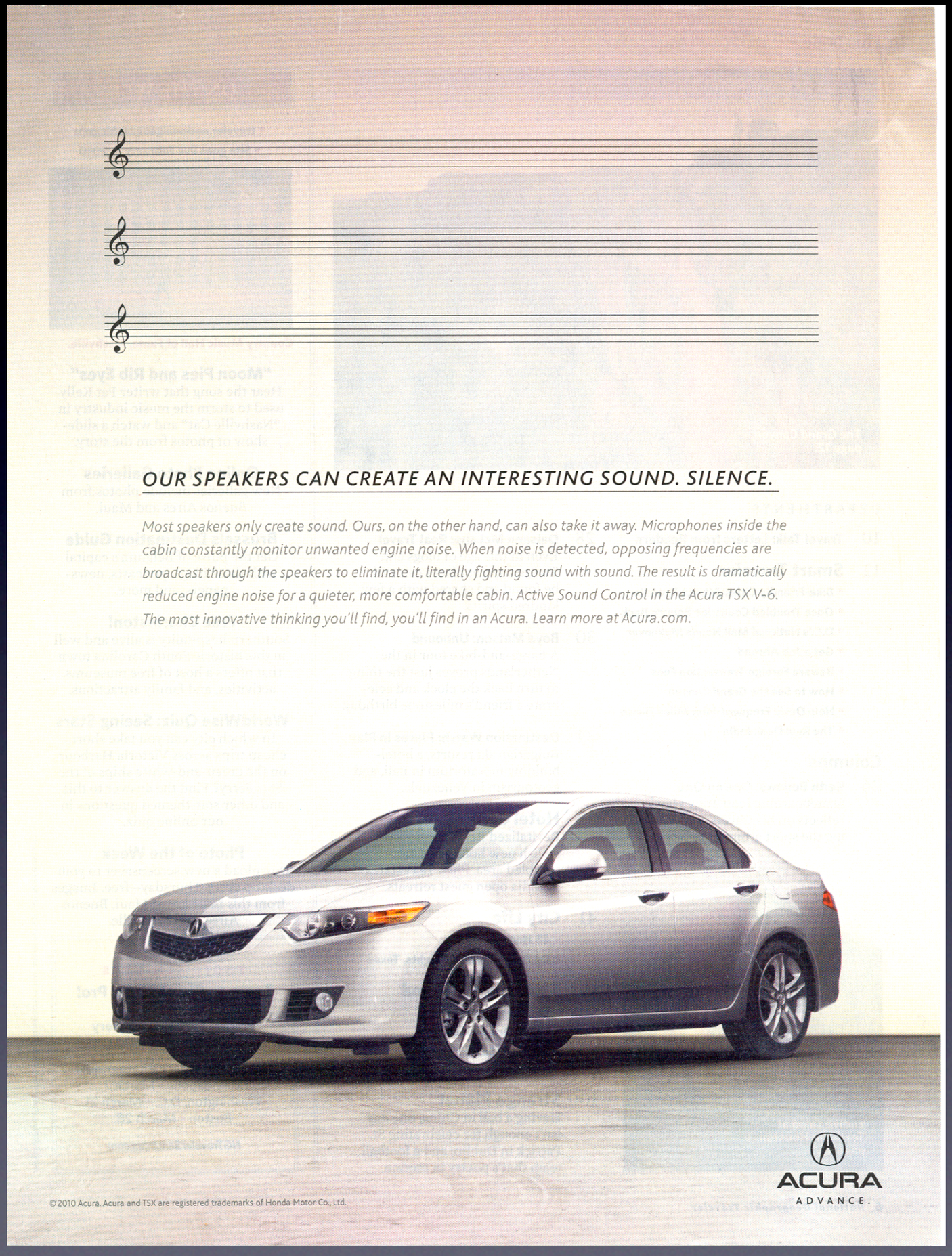
They are
already here



- Contain a microphone as sensor and a noise cancelling circuit (still able to hear 95% of speech range)
- Developed initially for for the Rutan/Yeager Voyager flight around the world.
- Coveted by pilots and air travellers.
- Cost about $400.

Smart Systems

They are already here



Concept Definition

- The concept of a smart system can be described as a “system that has intrinsic sensor, actuator and control mechanisms whereby it is capable of sensing a stimulus, responding to it, and reverting to its original state after the stimulus is removed.”

Concept Definition

- Integration of functions

  sensor, actuator and control mechanisms

Concept Definition

- Stimulus

  stress, strain, light, electric field,

  gas molecules, temperature and pressure,

  etc.

Concept Definition

- Response

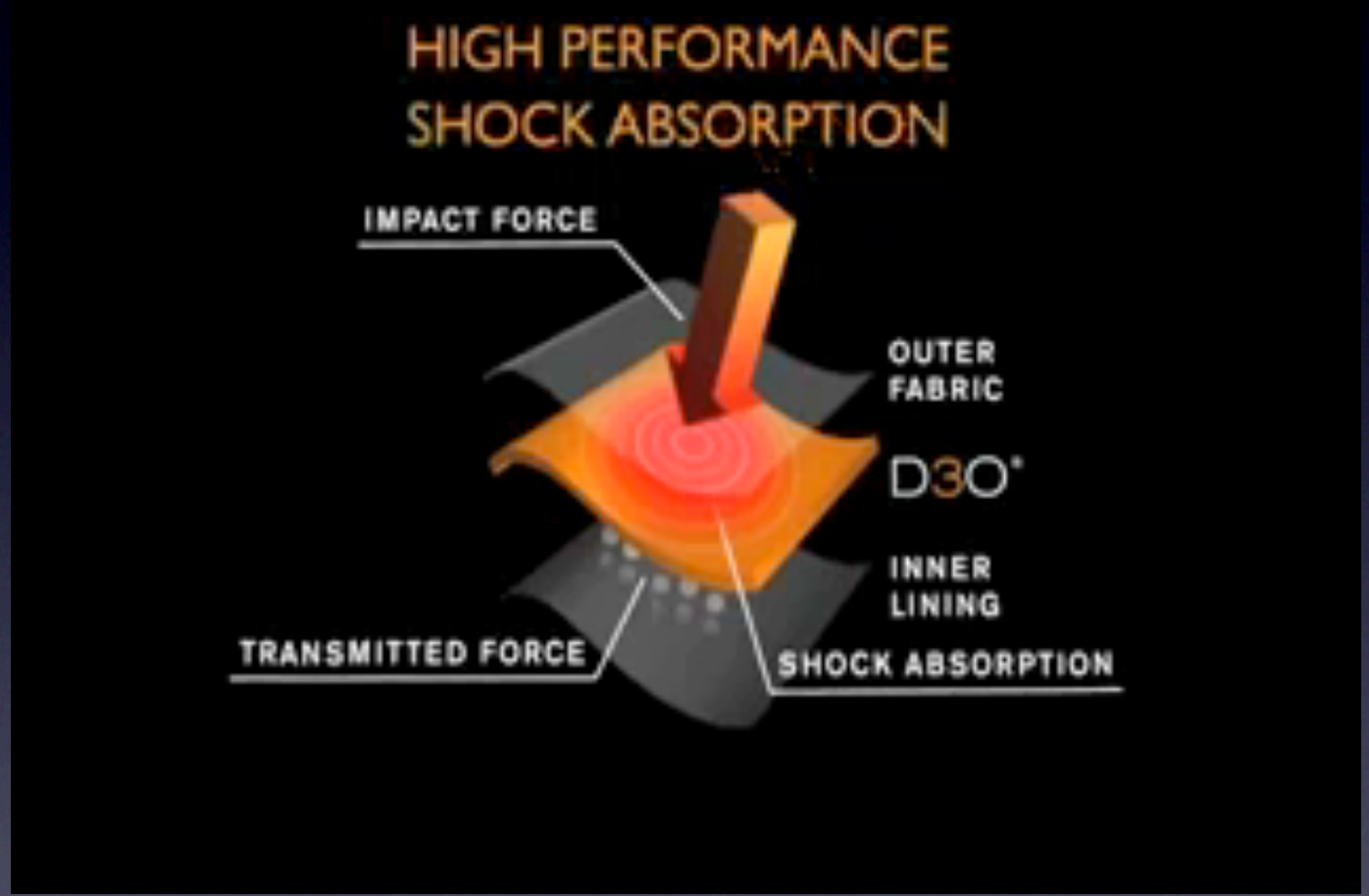
  motion or change in optical properties, modulus, surface tension, piezoelectricity or pyroelectricity, etc.

Definition of Smart Systems

- Smart Material

  Material that has the intrinsic or extrinsic capabilities to respond to an external stimulus in a functionally useful manner

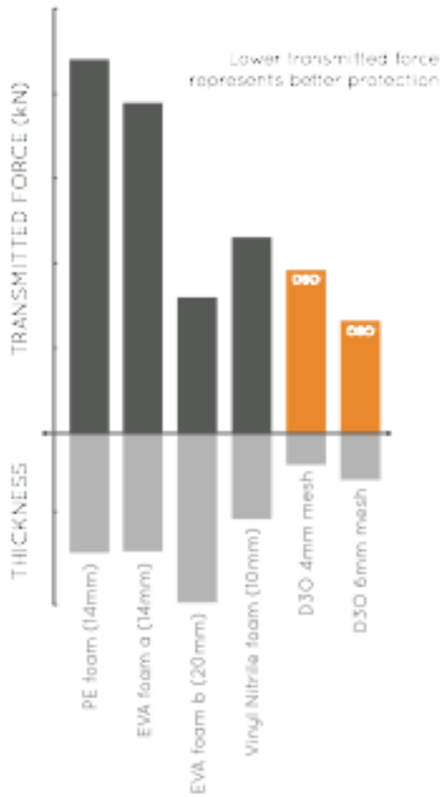
Smart Materials



D30 Impact Protection Materials - Graham Phillips; D30.com

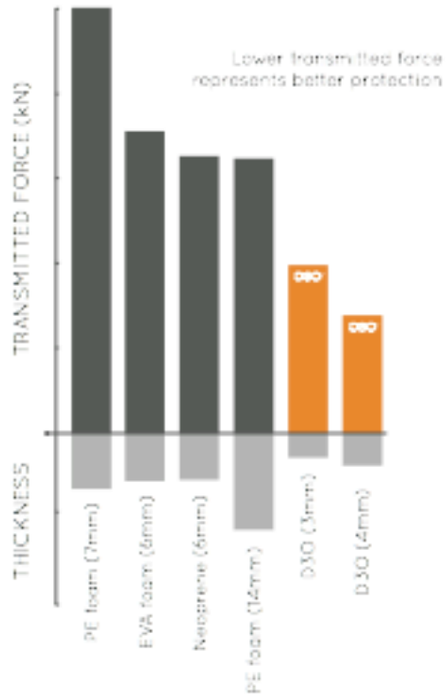
ST

COMPARATIVE IMPACT PERFORMANCE AT 20J*



SHOCK+

COMPARATIVE IMPACT PERFORMANCE AT 20J*



PLAIN SHEET

MATERIAL	THICKNESS (mm)	WEIGHT (g)
ST	3	113
	4	118
	6	282
SHOCK+	3	135
	4	226
	6	338

MESH SHEET

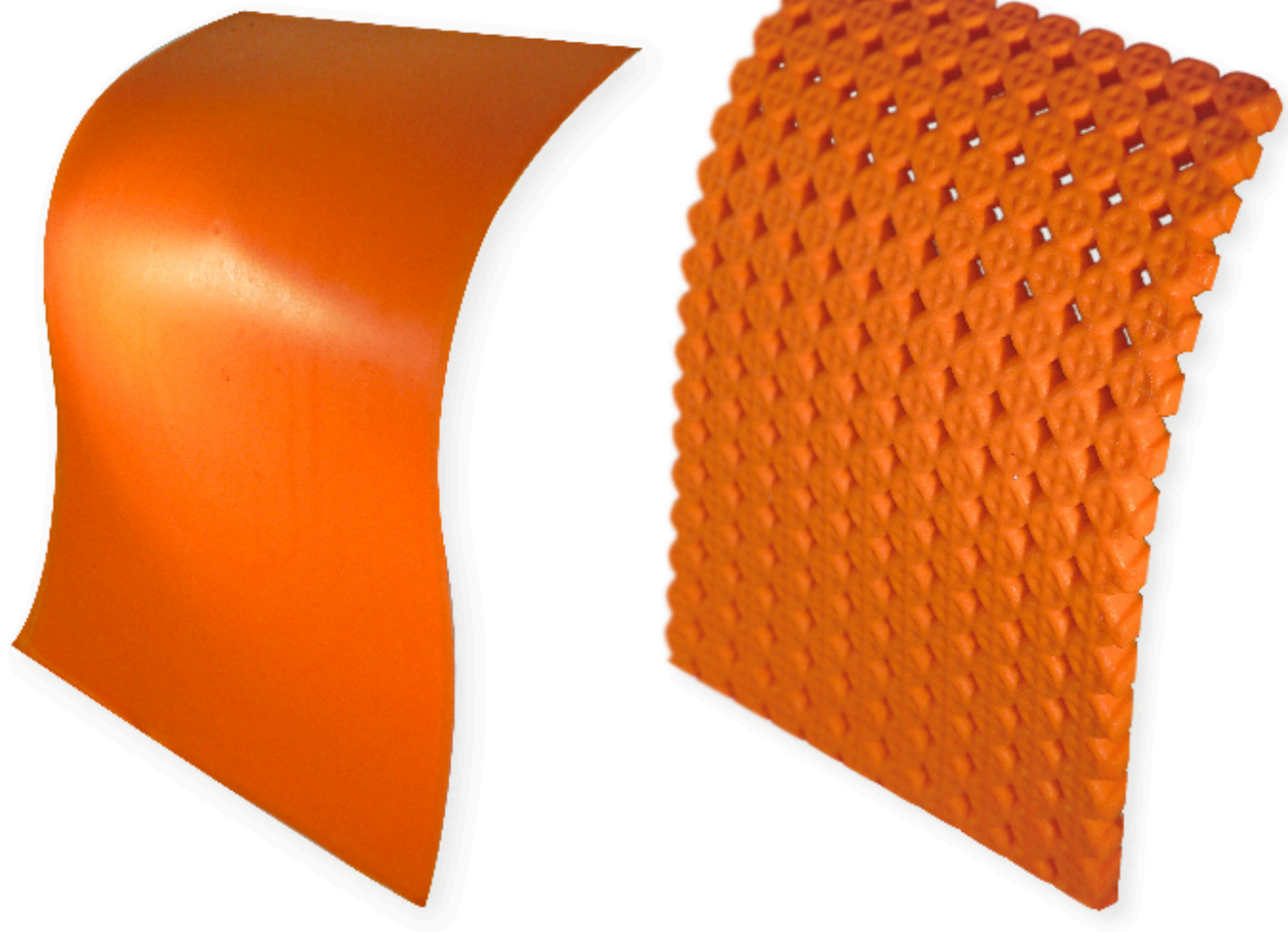
MATERIAL	THICKNESS (mm)	WEIGHT (g)
ST	4	205
	6	310
SHOCK+	4	247
	6	414

D30 Material characteristics

PLAIN SHEET
MESH SHEET

The plain and mesh sheets come in two materials: Shock+ and ST. The Shock+ sheet is more temperature stable and is fire retardant, whilst ST is lighter. Both materials, however, offer great protection and flexibility and are ideal for all markets.

- Great performance in extreme temperatures
- Non-Toxic



D30 Materials

Photochromic Glasses

- The glass version of these lenses achieve their photochromic properties through the embedding of microcrystalline silver halides (usually silver chloride), or molecules in a glass substrate.

- Plastic photochromic lenses rely on organic photochromic molecules (for example oxazines and naphthopyrans) to achieve the reversible darkening effect.

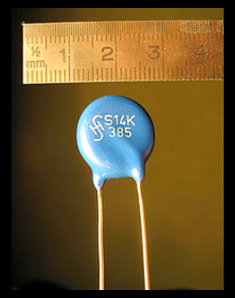
- The reason these lenses darken in sunlight is that they respond to UV found in sunlight.

Photochromic Glasses

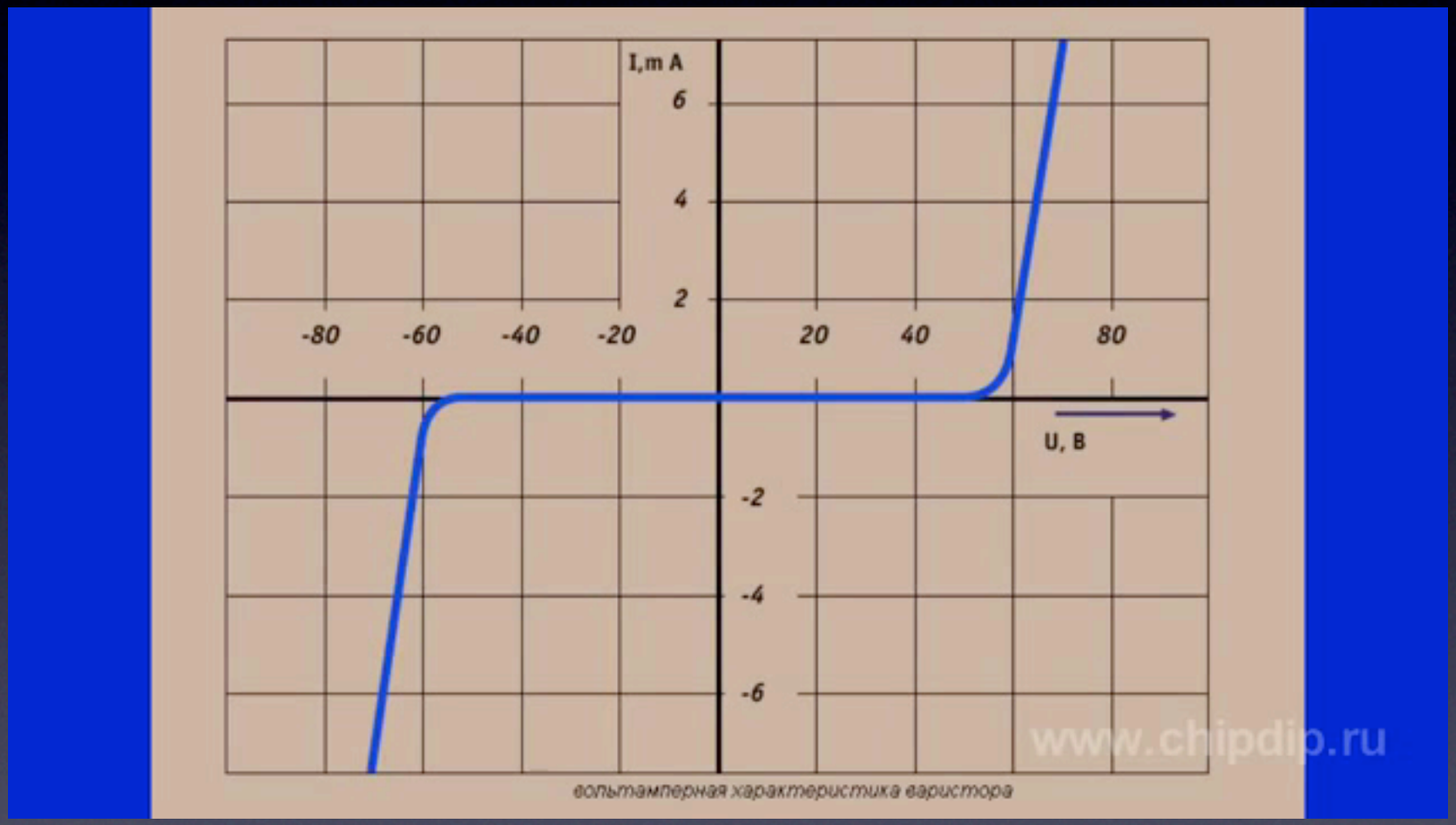
Transitions Lenses - Are They Right For You? http://www.youtube.com/watch?v=PNZAB0nJmU4

Definition of Smart Systems

- ZnO varistors are used as protection against high-voltage breakdown in power lines. When struck by lightning, the electrical resistance of these varistors decreases and current is passed to ground. Once the high voltage is removed, the resistance properties are restored.



Varistors



Operation Principle of Varistors http://www.youtube.com/watch?v=1tTo_OShkaQ

Definition of Smart Systems

- Smart System

  A smart systems integrates the properties of embedded sensors, actuators and control mechanisms in order to respond to a given stimulus in a functionally useful manner. Usually this involves implementing hardware and/or software control mechanisms.

Need for Smart Systems

- Optimizing response of large, complex systems
- adaptive response will cope with unforeseen circumstances
- enhance the range of survivability conditions
- provide early warning systems

Need for Smart Systems

- Perform enhancements otherwise not possible
- increase precision - better road handling ability or minimizing a satellite antenna's surface distortion
- control of accuracy under thermal or other disturbances

Need for Smart Systems

- Functionality
- lightweight
- facilitate preventative maintenance
- enable performance optimization

Shape Memory Alloys

Smart Materials Demo http://www.youtube.com/watch?v=VU-dChOfkAg

Smart Ssytem Classifications

- Passively Smart

  Systems have the ability to respond to a stimulus in a useful manner, without assistance of electronic controls or feedback systems.

Smart System Classifications

- Actively Smart

  Systems utilize feedback loops which accelerate the recognition and response process.

Smart System Classifications

- Very Smart (or Intelligent)

  Systems utilize the nonlinear properties of the sensor, actuator, memory and/or feedback systems to tune the response behaviour.

Components of a Smart System

- The most basic definition of a smart system involves the sensing of an environmental change and a response to that change. Usually this process utilizes electronic processing. In order to carry out these activities, a smart system must have the three components.

Components of a Smart System

- Sensor(s)

  To monitor environmental changes and generate signals proportional to the changing measurand.

Components of a Smart System

- Actuator(s)

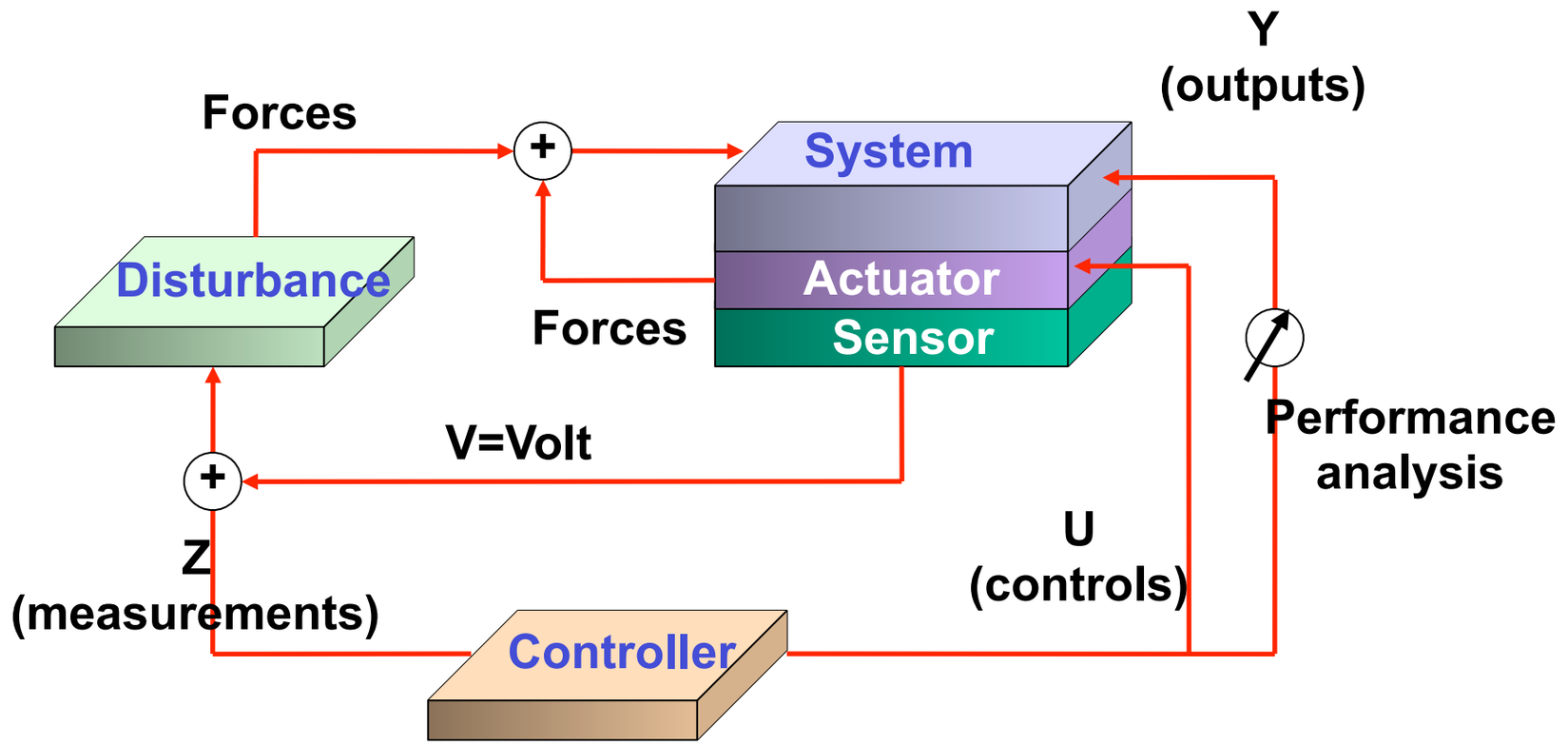
  The actuators are used to change the properties of the smart system in order to achieve the desired response.

Components of a Smart System

- Control Systems(s)

  The control system continually monitors the sensor's signal, processing the information in order to determine if action is required. If an action is required, then a signal is applied to the appropriate actuator(s).

System Component Schematic



Actuator Considerations

- A number of different actuators can be incorporated into a smart system in order to generate the appropriate response to a detected environmental variation. The type of actuator is dependent on a number of parameters.

Actuator Considerations

- Nature of the actuation

  Optical, magnetic, thermal, mechanical, chemical, etc.

- Nature of driving energy

  Thermal, magnetic, electrical, chemical, etc.

Actuator Considerations

- Interfacing

  Size, geometry, mechanical properties, etc.

- Properties of the actuator

  Displacement, force generation, hysteresis, response time, bandwidth, etc.

Sensor Considerations

- A number of different sensors can be incorporated into a smart system to measure a number of different environmental variations. The type of sensor utilized in smart systems is dependent on a number of factors.

Sensor Considerations

- Nature of measurand

  Radiation, magnetic, thermal, mechanical, chemical, etc.

- Sensor output

  Thermal, magnetic, electrical, optical, mechanical, etc.

- Environment

  Corrosive, thermal, magnetic, electrical, etc.

Sensor Considerations

- Interfacing

  Size, geometry, mechanical properties, etc.
- Operational properties

  Sensitivity, bandwidth, linearity, gauge length, operational range, etc.

Smart Control System Considerations

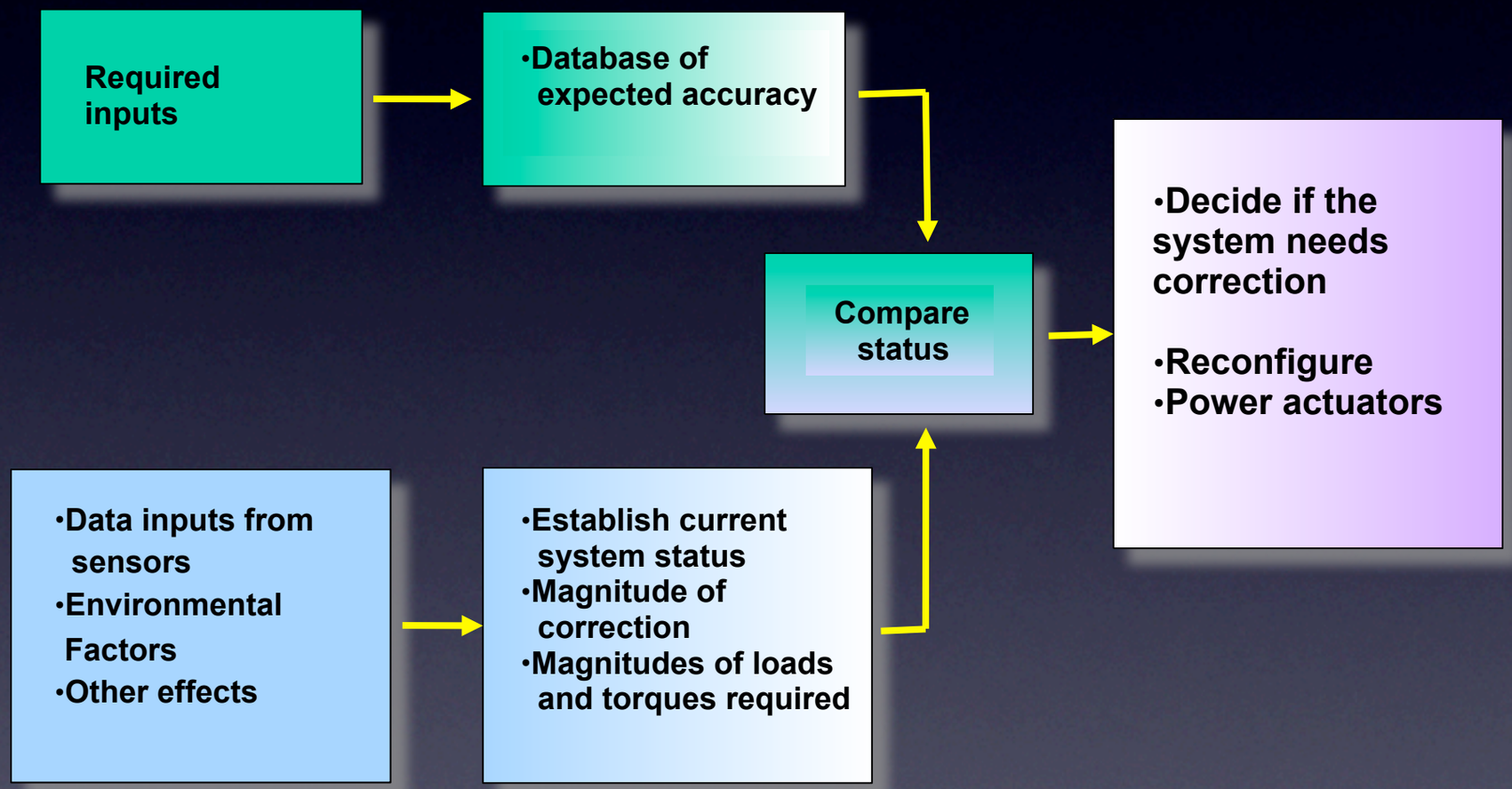
- The Smart Control System will provide feedback control for the sensors and actuators.
- The SCS will include the interfaces necessary for the operation of the sub-system modules

Smart Control System Considerations

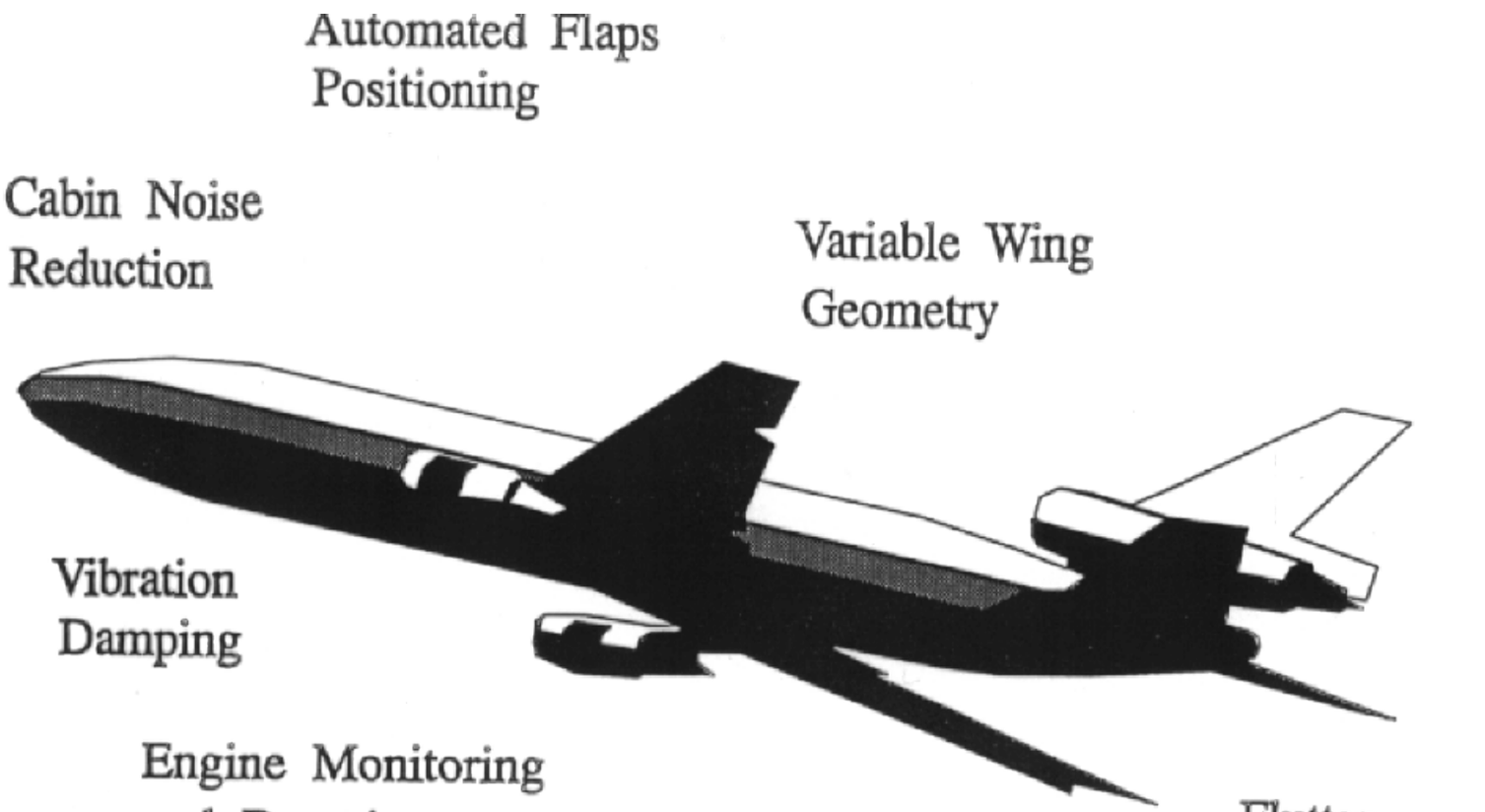
The SCS will consist of the following:

- Analogue-to-digital and digital-to-analogue converters
- Input signal amplification and filtering
- Control algorithms
- Digital signal processor (DSP)
- Output power supply

Functional Flow Diagram



Smart System Applications



Smart systems envisaged for application in aircraft.

Effects of Flutter

Aeroelastic Flutter http://www.youtube.com/watch?v=qpJBvQXQC2M

Flutter Testing in Airbus A380

Airbus A380 Flutter Test http://www.youtube.com/watch?v=qpJBvQXQC2M

Smart System Applications

Aerospace

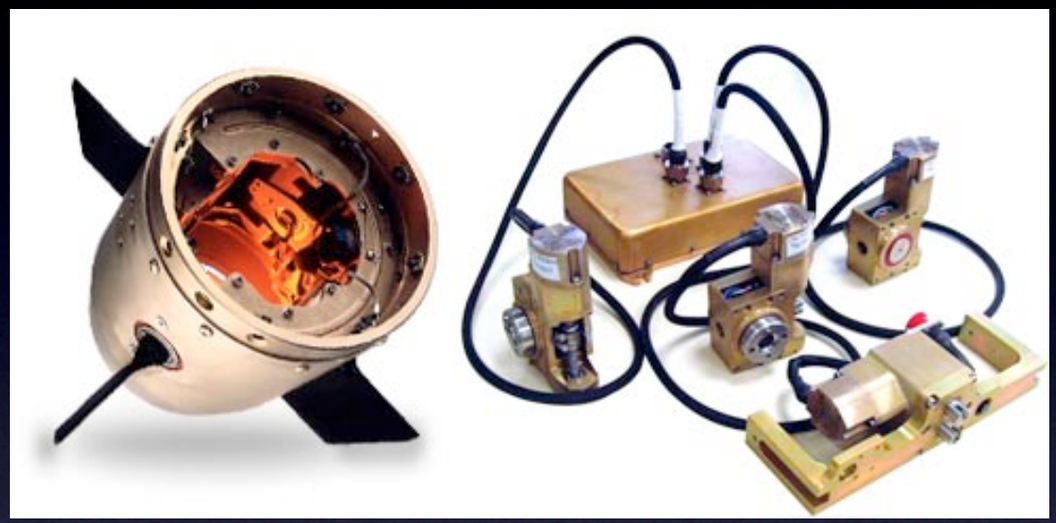
- Damage detection
- Vibration control
- Shape control
- Adaptive systems

Smart System Applications

Defence

- Firing accuracy of weapons
- Vibration and noise reduction in submarines
- Adaptive wings for aircraft and missiles

Fin Control Actuation Systems (FCAS) - Moog Inc



- The system controls the position of the missile fins in response to steering commands from the flight computer.
- The typical FCAS consists of four actuators and associated control electronics all integrated into a ring that matches the outer mold line of the missile.
- A single board computer, capable of processing all Guidance, Navigation, and FCAS control is integrated into the device.

Vibration and Noise Signature Reduction in Submarines

- Passive and active methods are used.
- Acoustic tiles are attached to the outside of all modern submarines.
- They are used to absorb active sonar scans, and absorb sound that is generated inside the submarine.

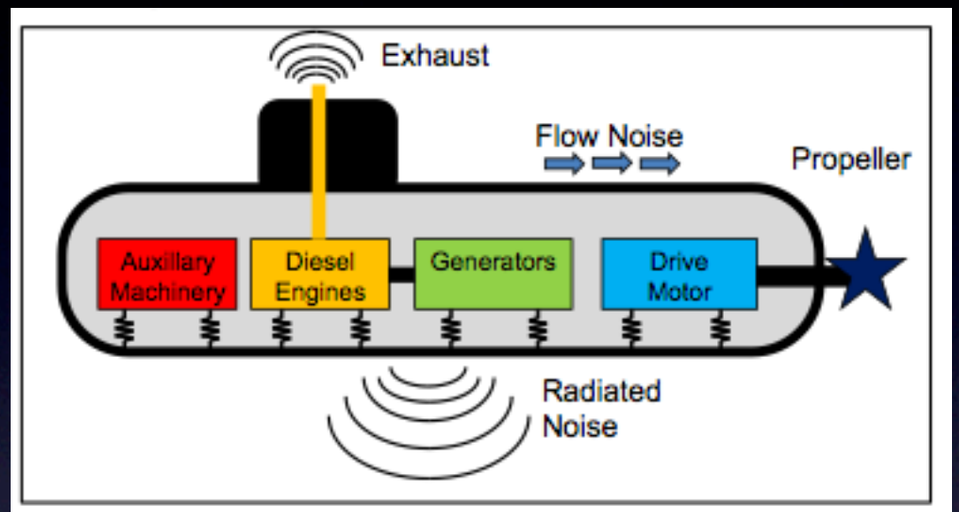
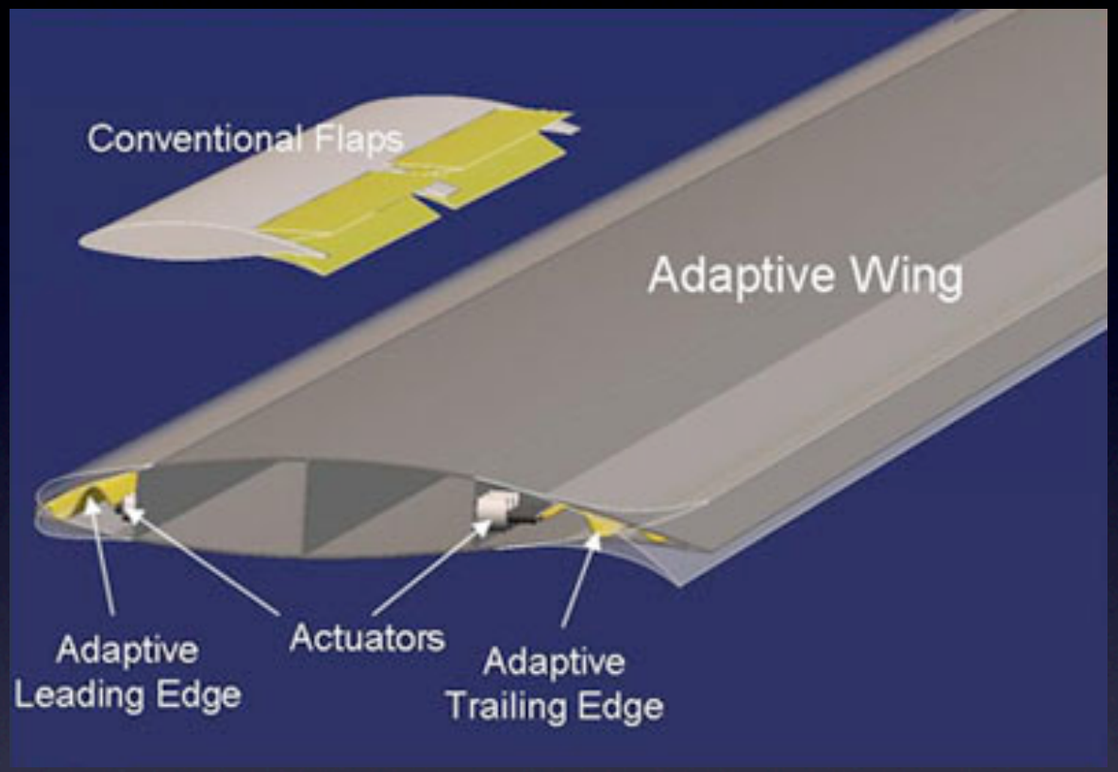


Figure 1: Noise and vibration sources on a submarine.

- As a submarine dives, greater water pressure is exerted on the acoustic tiles, which are made from rubber or polyurethane, making them less effective.
- Acoustic Cloaking technology has been gaining interest in defence applications where the acoustic tiles would enable a submarine to be invisible to sonar scans.

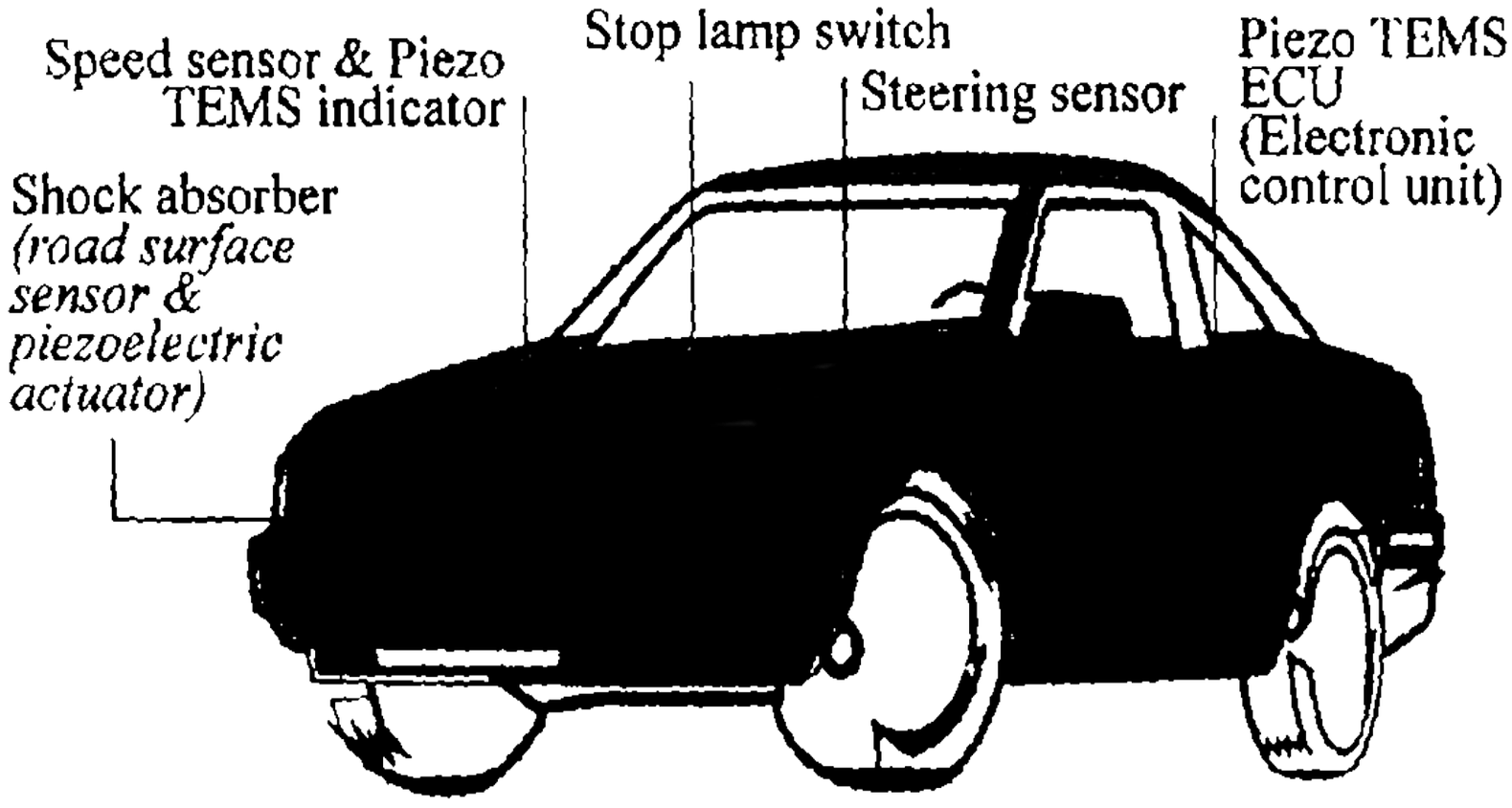
Recent Developments in Submarine Vibration Isolation and Noise Control - Carl Q. Howard, 2011.

Adaptive Wings

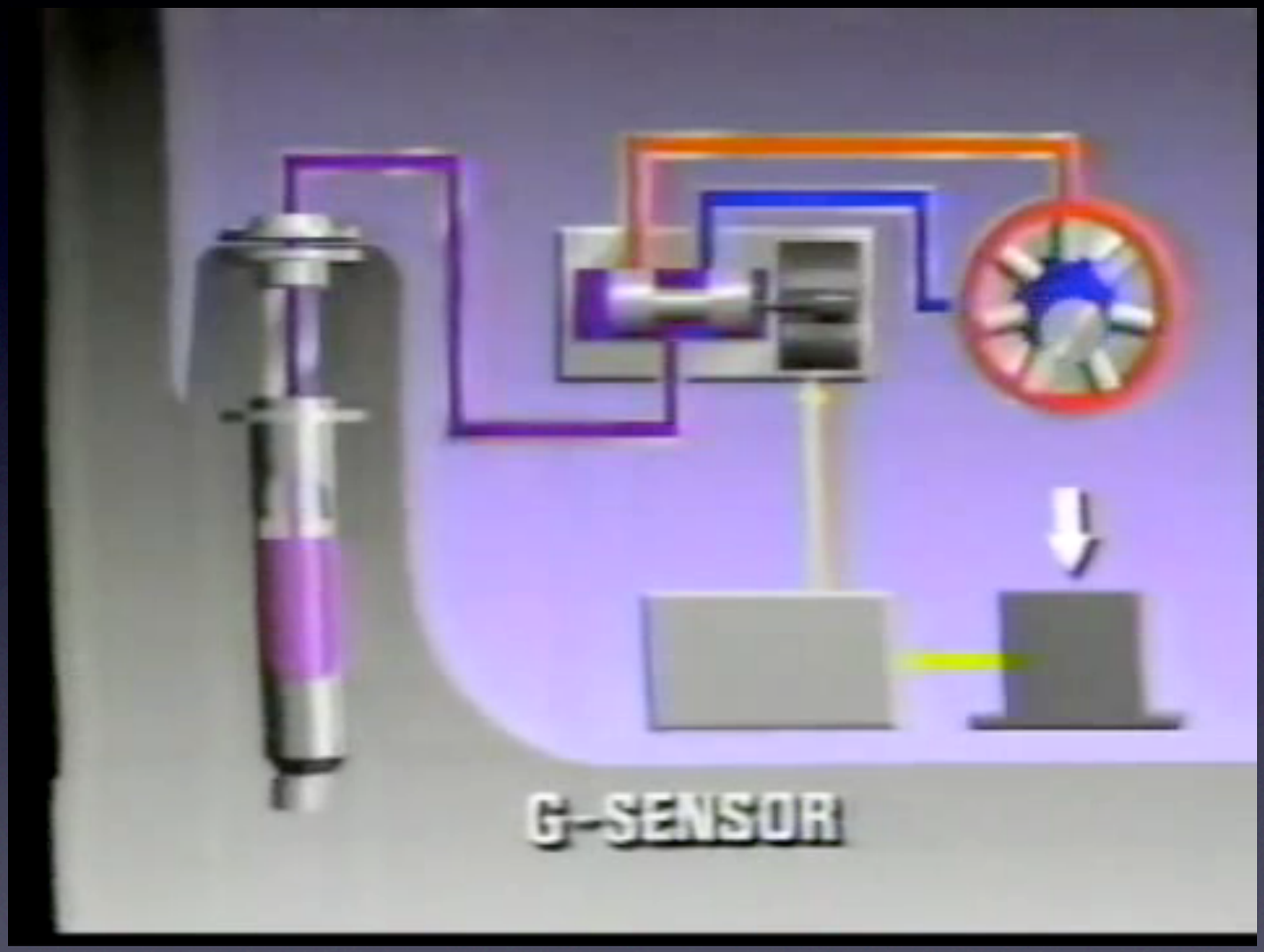


Airbus 380 Wing - Irfan Caliskan, Airliners.net

Smart Automobile



Smart Suspensions

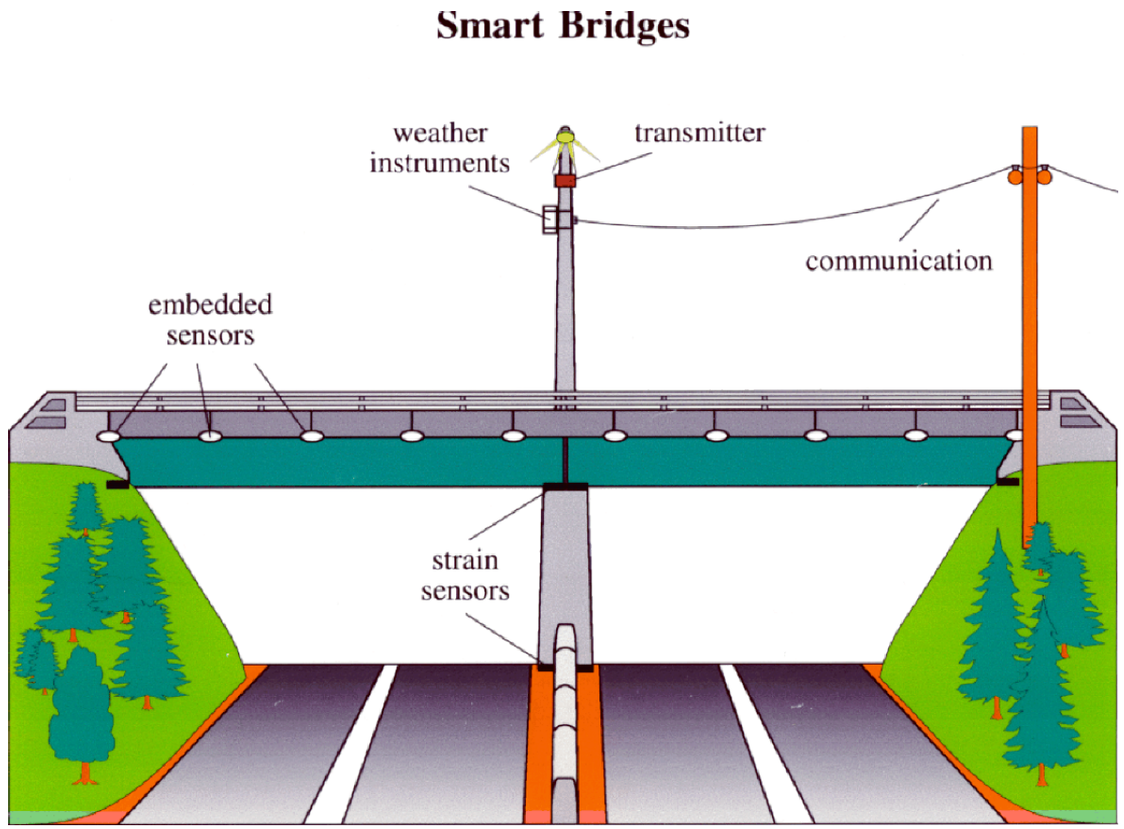


MW 1991 Infiniti Q45a Active Suspension Road Test http://www.youtube.com/watch?v=HnC-R3U5vO4

Automotive Applications

- Automotive
- Passenger comfort (noise control in cabin)
- Vibration control (active engine mounts)
- Health monitoring (smart sensors)

Civil Engineering Applications



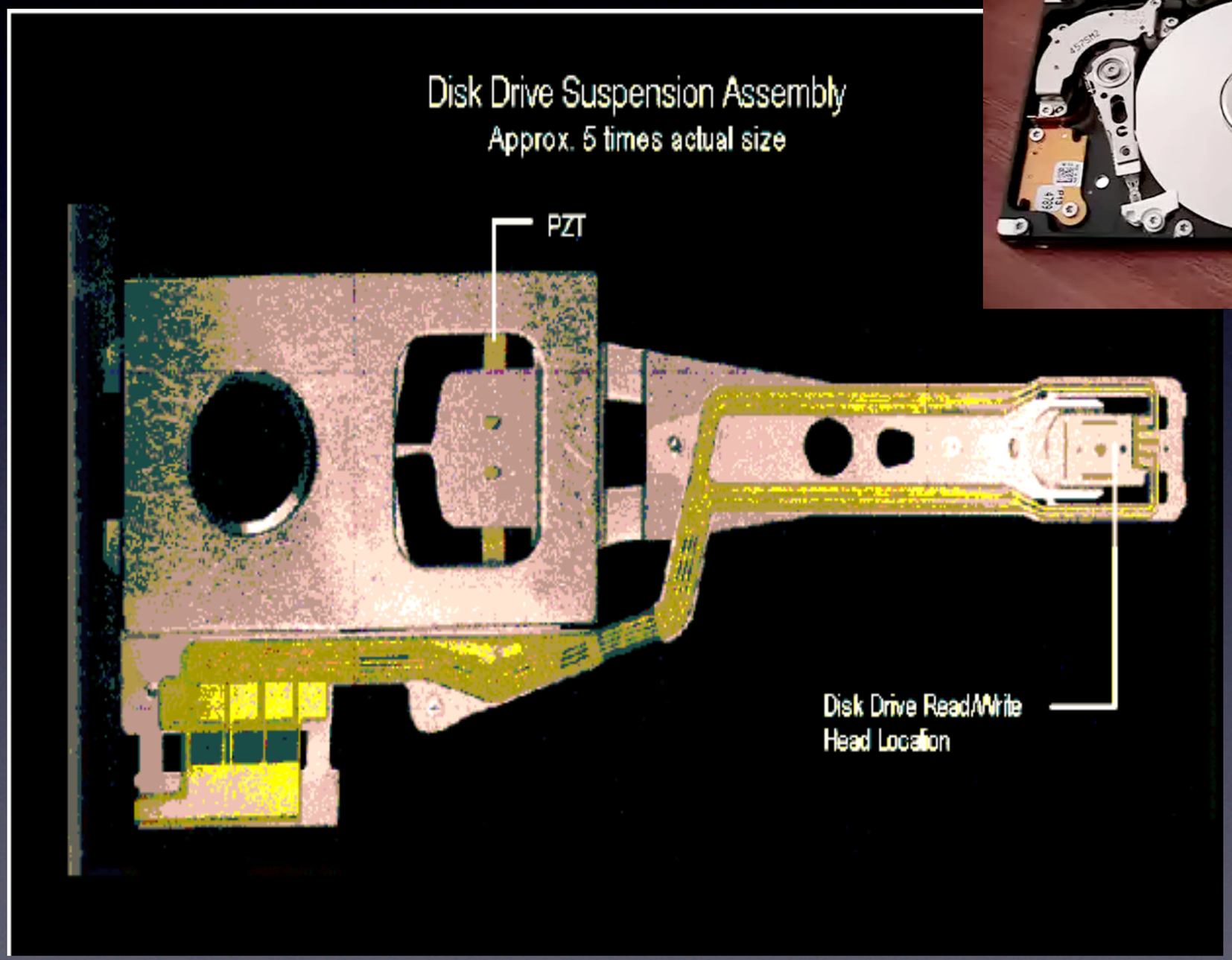
Civil Engineering Applications

Smart Bridge http://www.youtube.com/watch?v=fBszmOPEJkE

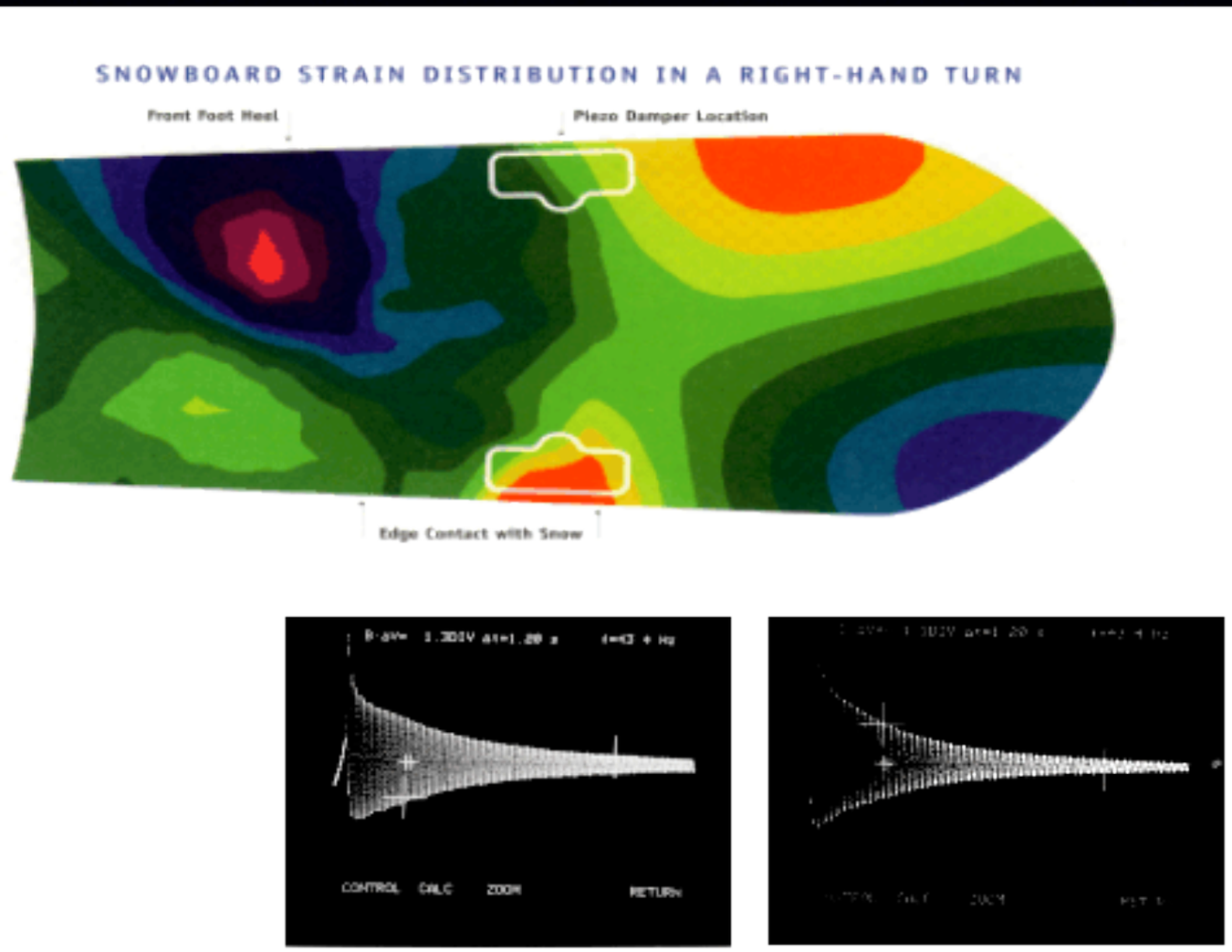
Civil Engineering Applications

- Bridges
- Earthquake protection

Computer Hard Disc Drive Head

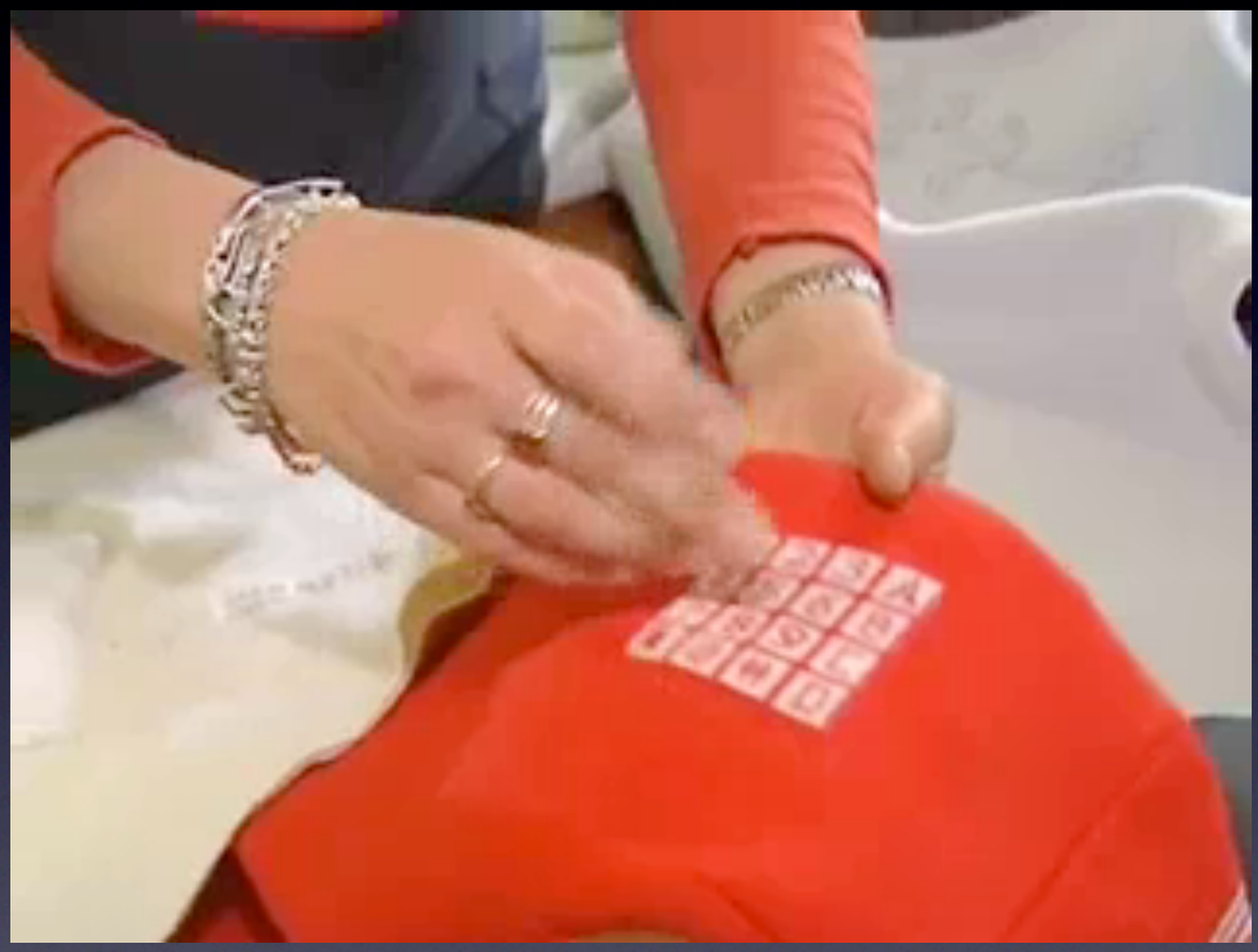


Active Skis


SNOWBOARD STRAIN DISTRIBUTION IN A RIGHT-HAND TURN
Front Foot Heel
Piezo Damper Location
Edge Contact with Snow

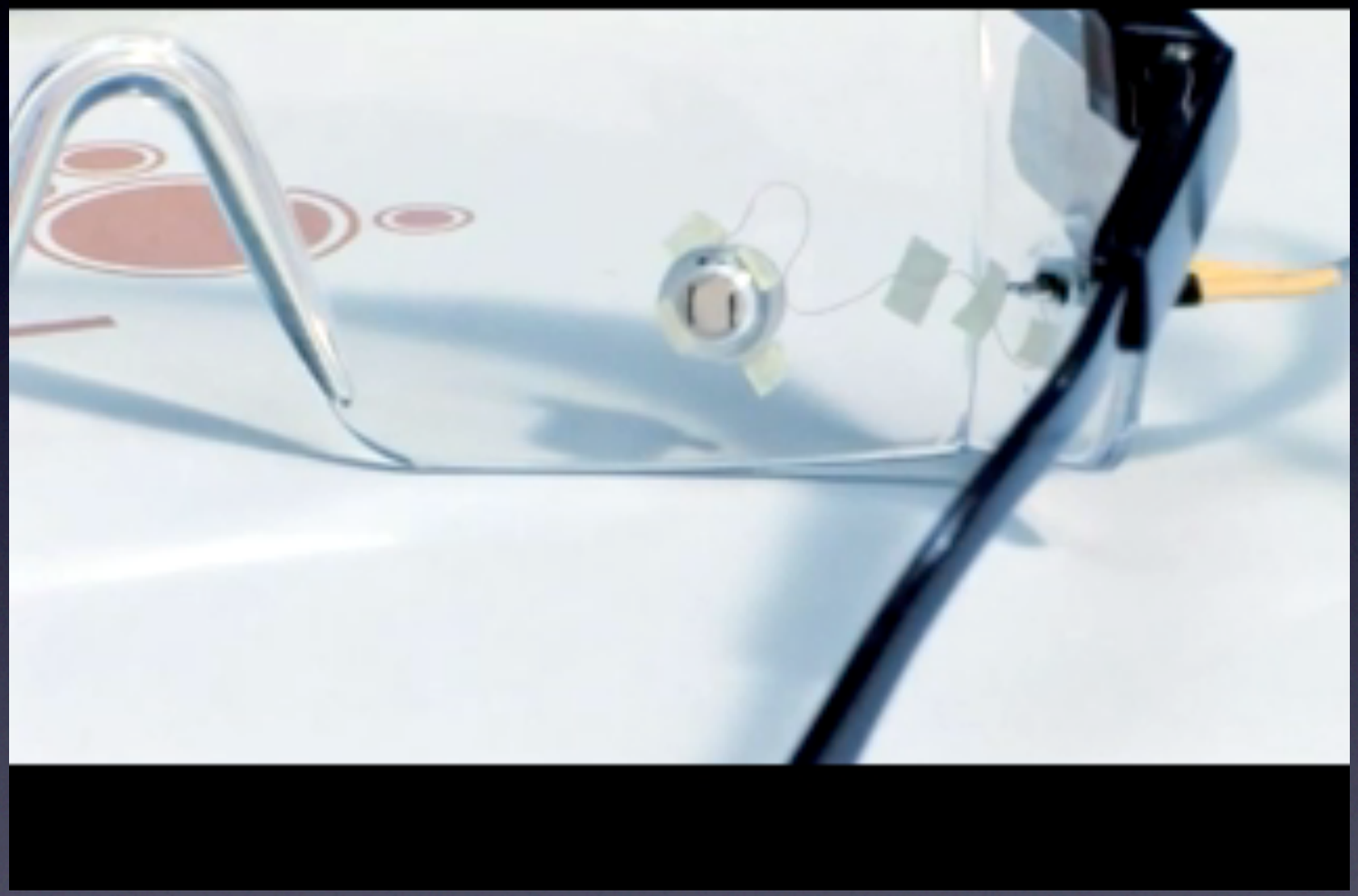
CONTROL
CALC
ZOOM
RETURN

Textiles of the Future



Textiles of the future http://youtu.be/bHLtZvbhn2Q

Plastic Electronics Technology

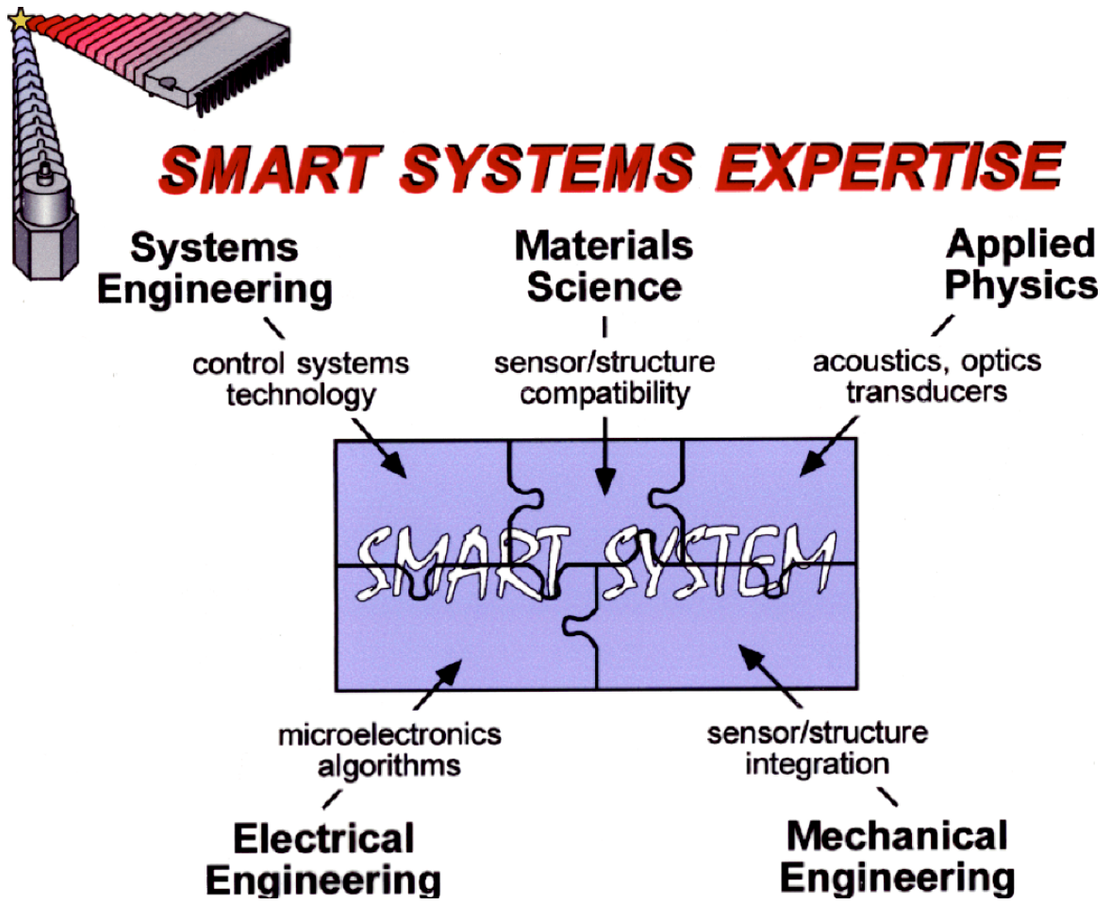


NANOMOL Plastic Electronics Technology http://youtu.be/QQYDBnI7K8g

Conclusions

- The current ‘state-of-the-art’ with respect to smart systems has been established.
- The relevance of these technologies has been established.

Conclusions



Conclusions

The emerging industrial applications are:

- Active Vibration Control (AVC)
- Active Noise Control (ANC)
- Active Shape Control (ASC)
- Active Health Monitoring (AHM)

Next

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Resources

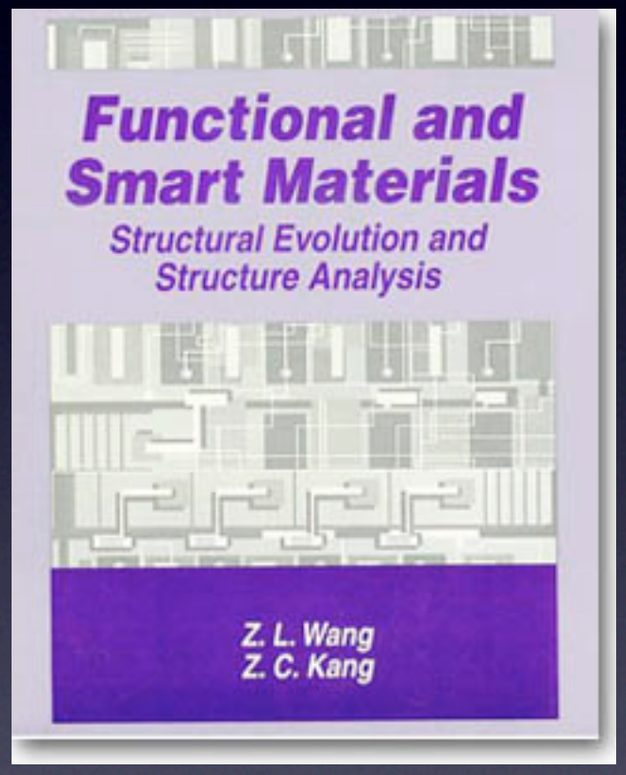
Smart Structures and Materials
(Artech House Optoelectronics Library)

by Brian Culshaw

This book introduces the enabling concepts that make up the so-called "smart structure" and presents a number of brief case studies to illustrate the applications of these concepts. It examines the domains of the individual technologies and defines the challenges faced by the integrator. The book is particularly effective for the potential system user.

Hardcover, 280 pages
Published January 1996 by Artech House Publishers

Resources



Functional and Smart Materials Structural Evolution and Structure Analysis

by Zhong Lin Wang and Z. C. Kang

(Plenum Press; 1st edition, January 15, 1998)
ISBN: 0306456516 (514 pages)

Plenum Publishing Corp., Attn: Dept. M99-95
233 Spring Street, New York, NY 10013-1578

Resources

Encyclopedia of Smart Materials, Volumes 1-2

Edited by: Schwartz, Mel © 2002 John Wiley & Sons

Description: This encyclopedia is the premier reference for material scientists, chemists, chemical engineers, process engineers, consultants, patent attorneys and students in these areas. An essential resource on the shelves of laboratories, government facilities, and academic libraries.

Resources

Smart Structures and Systems

Published/Hosted by TechnoPress. ISSN: 1738-1584.

Smart Structures and Systems, An International Journal of Mechatronics, Sensors, Monitoring, Control, Diagnosis, and Management airns at providing a major publication channel for researchers in the general area of smart structures and systems. Areas covered by the journal include - Sensors/Actuators(Materials/devices/informatics/ networking); - Structural Health Monitoring and Control; - Diagnosis/Prognosis; - Life Cycle Engineering(planning/design/ maintenance/renewal); - and related areas.

Structural Control & Health Monitoring

Edited by: Lucia Faravelli, Satish Nagarajaiah

Impact Factor: 0.982

ISI Journal Citation Reports © Ranking: 2009: 13/49 (Construction & Building Technology); 30/56 (Instruments & Instrumentation); 36/106 (Engineering Civil)

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S. Eswar Prasad,
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Mechanical & Industrial Engineering
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